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All communications should be addressed to the Editor.

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Notices of the Aëronautical Society of Great Britain.

Elections.

The following have been elected to the Society in the various grades:—

Associate Fellows.—Lieutenant Alexander Clark, Commander T. R. Cave Brown Cave.

Members.—Captain W. C. Gibbings, Major P. H. Wilson, D.S.O., R.F.A.

Students.—F. C. Smith, J. D. Frier, W. C. Boswell.

Associate Members.—E. S. Robinson Thorpe, R. H. Hollingsbee.

Appointments.

We are advised that Wing Commander Gerald Aldwell, R.N. (retired), has undertaken the general managership of the Aviation Dept. of Messrs J. S. White and Co., Ltd., of Cowes.

Major-General F. H. Sykes, Associate Fellow, has been appointed Chief of Staff to the Royal Air Force.

The Wilbur Wright Memorial Lecture.

This lecture will be given in June by Dr. W. F. Durand, Chairman of the American National Advisory Committee for Aeronautics, and Chairman of the European Commission of the American Aircraft Board. The title of the lecture will be: "Some Outstanding Problems in Aeronautics." Details will be announced in due course.

The Annual General Meeting.

This meeting will be held in the Offices of the Society, 7, Albemarle Street, London, W., on June 19th, 1918, at 5.0 p.m. Nominations for the Council should reach the Secretary on or before May 29th.

The Abstracts.

This month we publish the first of a series of Abstracts from the technical Press dealing with aeronautics. It is hoped to make these a feature of the "Journal" month by month.

STEEL TUBES, TUBE MANIPULATION, AND TUBULAR STRUCTURES FOR AIRCRAFT.

BY W. W. HACKETT AND A. G. HACKETT, OF OLDBURY, BIRMINGHAM.

Introductory.

The present decade will pass down into history notorious for many things good and bad. It will be styled a time of improvement in many ways. It will be remembered as covering the period of the world's greatest war, but it will also be remembered among all trades appertaining in any way to engineering as the age of progress in the manufacture and manipulation of steel tubing.

Independent altogether of the stimulus given to the use of tubing for structural work by the advent and advance of aeronautics, the uses to which tubing of steel and other metals is put has increased considerably during the past few years. Much, of course, has been due to the large output of cycles and motor-cycles, but in addition an immense quantity of tubing is used in the construction of motor-cars, and in a thousand other productions which it is unnecessary to particularise in this paper.

The section of tubular work in which we are more especially interested at the moment, however, is that which has relation to aircraft construction, and in this paper we hope to deal with some of the main features of this important subject, giving a brief review of the method of manufacture generally employed, of some of the difficulties that have had to be overcome, and of some of the forms of manipulation which it is possible to put upon good quality steel tubing. The latter part of the paper will deal with tests carried out on specimen tubes, under various conditions, and jointed together in different ways. All that we have to say will apply to seamless steel tubing.

Seamless Steel Tubing.

In dealing with such a subject as this other articles must be brought under review, such, for instance, as lugs and liners, as these enter so largely into the construction of articles built mainly of steel tubing. Mention will be made of cycle and motor-cycle experience in the use and abuse of steel tubing.

Seamless steel tubing is a product of modern times, some 35 years having passed since the first experiment was successfully carried through. Its commercial production has often made possible the manufacture of articles which could not otherwise have been made, and in other cases it has been the means of popularising articles which were having a very small sale, and which were even looked upon as freaks. Many present will remember the old bicycles which were built of gas pipes and solid pieces of iron, and will have recollections of the energy taken to propel these machines, especially up an incline! The coming of seamless steel tubing soon altered that, and a few years later cycle frames were being built of light gauge tubing, enabling a man to propel himself at 10 to 20 miles an hour on a structure weighing about 30lbs. Two things made the cycle a commercial success: pneumatic tyres, which made riding more comfortable, and light gauge steel tubing, which brought down the weight of the cycle to a minimum. A further word must be said for the pneumatic tyres, namely, that by minimising the shock to the frame they made possible the introduction of lighter gauge tubes than could otherwise have been safely used.

How Seamless Steel Tubing is Made.

To commence the manufacture of a seamless tube a solid billet of steel, well hammered and rolled, is taken. This billet must be carefully examined for various

faults, and any lamination or surface defect removed by chipping, or else the outside of the billet must be turned all over. The usual practice when the latter is done is to turn about $\frac{3}{8}$in. off the diameter of the billet.

Hot-Rolling.

The first operation is then to pierce a hole. Two ways of doing this are in general use: one is by means of a hydraulic press, similar to the method of piercing shells so common in this country to-day, and the other by means of a rotary piercing machine. The billet, first centred with large shallow holes, is heated to about 1,200 deg. C. and fed between rolls having a curved outline and set at an angle which imparts a forward movement to the billet as it is rotated. Great pressure is used (which causes the billet to tend to open along its axis), and the billet is forced against and over a pointed mandril held on the end of a stout rod, which butts against a bracket at a distance of about 7ft. from the centre of the rolls. A billet, 4ins. diameter by 24ins. in length, will be made in one operation into a tube about 4ft. to 5ft. long. The pierced billet is then taken to another machine which is provided with upper and lower rolls having semi-circular grooves of various radii, and by a series of operations is rolled into a tube of the required size. The tube is passed over mandrils to give the required thickness.

A much quicker process of rolling mild steel tubes is by means of Pilger rolls; but for high carbon steel or chrome nickel steel this process has been found to be unsuitable.

Cold-Drawing.

The first operation in the cold-drawing mills is that of "tagging," the hollow bloom (as the rough rolled tube is called) being reduced at one end by suitable semi-circular tools in a power-forging hammer. The tube in the drawing operations to follow will be pulled through the dies by means of the "tag" thus formed. A small hole is also put into the tube at the point where the tag commences, in order to allow acid and water to work through the tube in the subsequent pickling and swilling processes. After being "tagged" the tube is annealed, pickled in a bath of acid to remove the scale, and then swilled in clean water. Following this, the tube is dried and then immersed in a solution of soap, or in oil, to lubricate it for the drawing operation. It is now ready for drawing.

There are two methods of cold drawing in general use. One is by drawing down the outside diameter of the tube upon a long bar of uniform diameter and then passing the tube, while on the bar, through rolls fixed in a "reeling" machine, which is similar to that used in the rotary piercing operation. In carrying out this method the tube is put on to the bar, which must of necessity be smaller than the bore of the tube to be drawn. The tube and the bar are then pulled through a die of hardened steel of such a bore as will give the proper reduction of gauge to the tube. The tube is gripped on the "tag" by means of "dog" jaws sliding on inclined planes. The "dog" is moved along the draw-bench by hooks which are dropped into the links of an endless chain. The chains move at a speed of from 12ft. to 35ft. per minute, according to the class of material to be drawn. This process of cold drawing permits of a greater reduction of thickness at each draw than can be obtained by the more usual process of plug drawing, but is rather harsh on the material, and the expanding of the tubing (already hardened by drawing) to allow the mandril to be extracted sometimes causes splits and fractures. These are more likely to appear if this process is used after the tube has been drawn to a light gauge.

The second method is that known as "plug drawing," and is more usually adopted; in this case a short, hardened mandril is screwed into one end of a long bar. This bar is screwed at the other end into a larger piece of steel known as the "back sleeve," which is screwed and fitted with a nut at either end. This sleeve has an axial movement of about 9ins. in the back casting of the draw-bench.

The nut at the back is used for the purpose of adjusting the position of the mandril in relation to the die.

The tube is threaded over the mandril and the " tag " is passed through the die, which rests against the die plate. Immediately the tube is gripped by the " dog " it commences to move, the mandril at the same time being drawn forward into position by means of a rope or chain. A reduction in gauge thickness and diameter, with an increase in length, is the result, due to the walls of the tube being drawn down between the mandril and the die. The usual reduction by this method is about a gauge and a half per draw on low carbon steel. The operation of cold drawing hardens the tube to quite a large extent, and subsequent annealing is necessary.

Annealing.

A properly annealed tube showing an ultimate tensile stress of about 30 tons per square inch should give about 38 tons after undergoing the drawing operation. To properly prepare the tube for further cold drawing it is therefore necessary to anneal after every drawing operation, which means it has also to be pickled, washed, dried, and lubricated. A hollow bloom 1⅞in. diameter by 8in. gauge would require nine or ten " draws " to make it into a tube 1¼in. by 22in. gauge. The annealing is carried out in suitable muffles, usually at a temperature of about 600 deg. to 650 deg. C., until before the last " draw," when a temperature of about 850 deg. C. is advisable. In the case of light gauge tubes, this should be done by " close " annealing, as the scaling and blistering of a light tube by " open " annealing would be fatal.

When a tube has been drawn to about 7/16in. diameter there is great difficulty experienced in drawing on a mandril. The usual practice is to finish ⅜in. diameter tubes and smaller by reducing the diameter only, termed " sinking." The condition of the tube finished in this way is not so good as when finished on a mandril, the strength of the tube being less. From experiments made, tubes from .5 per cent. carbon steel finished by " sinking " show about the same tensile strength as tubes from .35 per cent. carbon steel finished with the usual " draw " on a mandril.

Chrome Nickel Tubes.

The advent of aeroplanes and airships has given rise to a demand for steel tubing of a higher class than before, tubes of high carbon and alloy steels being called for. This has meant careful investigation in order to find the best heat treatment to be accorded in each particular case. The first attempts at drawing chrome nickel steel were scarcely a success, and many breakages of mandrils and even draw-benches resulted from the unsatisfactory annealing of these tubes. Chrome nickel tubes are now being successfully drawn by the same methods as are used for mild steel tubing—by means of " plug drawing "—but very great care needs to be taken in the annealing.

The amount of reduction in gauge per draw is less than half that which is usual in the drawing of mild steel, but in spite of this the wear on mandrils and dies is very great.

A typical analysis of chrome nickel steel is as follows :—

Carbon	.3 per cent.
Silicon	.16 ,,
Sulphur	.03 ,,
Phosphorus	.03 ,,
Manganese	.45 ,,
Chromium	1.10 ,,
Nickel	4.00 ,,

Such a steel, when air-hardened, has an ultimate tensile stress of about 100 tons, but a low elastic limit to a maximum value of about 70 tons. Tempering will raise the yield point and at the same time slightly reduce the ultimate stress. This steel is being much used for aeroplane axles. One feature that should be mentioned here is the very serious effect of sulphuric or muriatic acid on hardened chrome nickel steel tubing. It has the effect of making the material exceedingly brittle. Fig. 1 shows a piece of tubing cut from an axle and considerably ovalled, after being hardened, without splitting the tube; also one from the same piece that has been pickled. It will be seen that this has cracked, although the tube is still almost circular. It is therefore inadvisable to use acid to remove scale from a hardened chrome nickel steel tube; but the injurious effect of the acid can be almost entirely removed by suitable heat treatment.

Acid affects other high tensile steels in the same way, but to a less degree, and has a considerable effect even on mild steel.

Section Tubing.

Section tubing has been extensively called for by aeroplane designers, and streamline tubing is used to quite a large extent. The first streamline tube our Company (Accles & Pollock, Limited) were asked to make was designed by Mr. Howard T. Wright in 1908, and is a section that is very near to the recognised standard of to-day. Section tubing, the streamline-shaped tube especially, is much easier to make if straight sides are avoided, as straight or concave sides compel the use of mandrils and add to the difficulty of production. There are three ways of making sections from seamless tubing, namely, by drawing, rolling and pressing. Pressing is only practicable on fairly short lengths. In drawing there is a slight reduction in periphery in passing from the round, but in rolling or pressing it remains the same.

Some Difficulties Overcome.

It will be useful in this paper to review some of the trouble we have met with in connection with other trades where tubing has been used to a great extent, and to mention some of the failures, as the same or similar faults may occur in aeroplane construction. When the Bowden brake was first used on cycles and motor-cycles the practice followed was to drill the tube near the handlebar lug to allow the cable to pass through, and this resulted in a large number of breakages. This difficulty was overcome by drilling the holes through the lugs; but many accidents occurred before this practice was adopted. Under an alternating stress a tube which has been drilled, unless properly reinforced, is very likely to fail. A series of running tests on drilled and undrilled tubes has shown that when stressed up to near its elastic limit the undrilled tube has in many cases 10 to 20 times the life of the drilled tube. (See Charts Nos. 1 to 11.) It is often the case that the harder the tube the greater the risk of breakage through a hole. One way of breaking a hard-drawn tube, adopted in tube mills, is either to "nick" the tube on one side with a file or to punch a hole in one side and then break by striking the tube on a block or anvil.

Quite recently we have carried out a large number of important tests on a special type of alternating stress testing machine which we had built. This machine, together with many of the tests carried out and the results achieved, was to a great extent due to the enthusiasm and foresight of Lieutenant-Commander H. N. Wylie, R.N.V.R., and Lieutenant R. W. Fieldwick, the Resident A.I.D. Inspector at our Works, and to whom we wish to express our thanks for help given.

The design of the machine is very simple, and is shown by Fig. 2. Fig. 3 also gives some interesting details of the chuck and weight attachment.

Various results of tests carried out on the machine referred to will be given during the course of this paper.

Badly Designed Cycle Lugs.

Another series of failures was caused by unsuitable lugs. Some of those used in the earlier days of motor-cycling had very strong outlets, and case after case of tube failure occurred. The tubing sometimes broke off so cleanly as to give the appearance of having been cut through. The broken tubing could be flattened, thus proving it was ductile and in a proper condition for its purpose. In order to prove that the fault lay in the excessive strength of the lugs, a series of experiments was carried out a number of years ago. A lug, as generally used, was tapered off at one outlet and left strong at the other. A piece of tubing of the usual gauge and quality was brazed into the lug and the lug firmly secured to a plate. The ends of the two tubes were then moved by eccentrics and connecting rods giving a ½in. movement at a speed of about 400 alternations per minute. Each time the experiment was tried the tube broke off cleanly close to the thick outlet, whereas the tube at the tapered outlet remained intact. (See line drawing, Fig. 4, and photographs, Figs. 5 and 6.)

Chart No. 1, given at the end of this paper, is a record of alternating stress tests taken to determine the value of "blueing" steel tubes. In these tests two types of grips were used, as indicated by the sketches at the foot of the chart, and two points were proved, namely, the beneficial effects of "blueing" and the increase in the life of a tube when held by a grip having a tapered outlet. Another interesting feature of the test was the spiral form of the break, shown in the photograph which follows the chart mentioned.

Another interesting test was as follows:—After brazing the tube into a lug with respectively thick and tapered outlets similar weights were applied to the ends. The tube in the tapered outlet bent with an easy curve, but that at the other end bent abruptly close to the thick outlet. (See photographs, Figs. 7 and 8.)

Front Forks for Cycles.

It has been proved to the satisfaction of many cycle and motor-cycle engineers that to keep on merely increasing the gauge of a tube that appears to be too weak for its work is not always good practice. For instance, take the case of the front fork tube as used on the ordinary cycle. This tube has proved of ample strength for use on the excellent highways of this country, but for Continental roads something better was wanted. Some years ago we supplied a large quantity of front forks produced from 19-gauge tubes to Russian cycle manufacturers. We were asked to increase the thickness to 18-gauge, on account of a number of breakages occurring. We did so, but matters were not improved, and we were then requested to further increase to 17-gauge. There was still no improvement; indeed, the number of breakages increased. The forks all broke off where they were brazed into the crown, and we were asked by the Russian manufacturers to help them out of their trouble. One way of doing this would have been by using a suitable liner or sleeve, but we tried another method, which proved quite successful. We brought back the gauge of the tubes to 19 where brazed into the crowns and tapered the gauge to 22 at the bottom ends. This proved effective; a lighter article by about 40 per cent., from the same quality steel, thus standing the strain successfully. This result is accounted for by the fact that the shock was more equally distributed along the tubing, due to the strength being reduced, gradually, away from the brazed portion, whereas in the plain gauge tubing the whole of the movement was concentrated in a very small space near the crowns.

Tapered Tubes.

Tapered tubes could, in our opinion, be used in aeroplane construction to a much greater extent than at present, especially as struts or spars.

Alternating tests as follows were carried out at 400 revolutions per minute on 1in. by 20-gauge steel tubing, using two parallel lengths and two pieces tapered $\frac{1}{2}$in. per foot. A weight of 111.56lbs. was suspended on each tube at a distance of $12\frac{3}{4}$ins. from the grips, giving 25 tons stress. The plain pieces broke after 20,585 and 30,390 revolutions respectively, as against 23,557 and 38,225 revolutions respectively by the tapered pieces. The weight of the plain tubes was $6\frac{3}{4}$ozs. each, and that of the tapered tubes $6\frac{1}{4}$ozs. each. In both cases the break on the plain tubes was straighter than on the tapered one. (See photograph, Fig. 9.)

There are several ways in which to taper a tube. A method much in use is that of swaging, but this is a most unsatisfactory way, as the tube is not kept round whilst being reduced. Swaging tools cannot be quite circular, as a certain amount of "backing off" must be given to them, or the tube will be pinched and crumpled. The continued deforming of the tube during this operation causes it to split if it is much reduced, and the steel is left brittle. Tapering is more successful if done on rolls, as it is then possible to keep the tube round, and the steel is left in a much better condition. In reducing the tube by tapering it is thickened in gauge roughly by about two gauges in a reduction of 50 per cent. of its diameter. A tube of $1\frac{1}{8}$in. by 20-gauge would thicken to 18-gauge if tapered down to 9/16in. diameter. If uniformity of gauge be aimed at, it would be necessary to thin the tubing before the tapering operation. This can be done by drawing. It is even possible to make a tube tapering both in diameter and thickness if such is required.

Tubular Liners or Reinforcements.

Considerable attention has been given to the matter of liners as reinforcements to tubes. In cases of trapped or flattened ends of struts a piece of strip steel is often inserted and soldered or riveted into position. This is not good practice, as the tube is not strengthened beyond the point at which it is flattened, and it is well known that, without some additional strengthening, a tube is always weakest at the point where the change of shape begins. If, before flattening, a tubular liner of a gauge equal to about half the thickness of the piece of strip steel is inserted to extend some distance beyond the trapped portion, a much better result is obtained. Various compression tests have been carried out from time to time, and the tubular liner has always proved to be superior. Photograph Fig. 10 shows actual sections through the two types of traps, and Fig. 11 sets forth another point regarding this particular class of work, namely, the importance from the standpoint of strength of leaving the walls of the tube untouched as far as possible along the flattened portion.

A liner, however, to be really efficient, should be brazed or soldered to the tube. A series of alternating stress tests has proved this point. Many liners used in tubular constructional work are not fixed, and consequently do not prevent the tube breaking, but may be sufficient to avoid accidents resulting from such breakages. Take, for instance, a front fork tube on a motor-cycle. The liner, often a long one, is put in because this tube has frequently failed at the lugs and serious accidents have occurred, but the position of the liner in the fork makes it very difficult to solder or braze in its place. However, if a fork tube should break, the liner will save the situation.

It is not wise to make a liner stronger than the tube it is to reinforce unless the ends of the liner are tapered off gradually or weakened by serrations. When the ends are serrated and the liner is not brazed or soldered into the tube this

serrated portion is seldom of any value, as it quickly takes a " set " away from the tube when it has been subjected to a bending stress.

Perhaps the better way to reinforce tubular parts is by means of strengthening " sleeves " brazed or soldered to the outside of the tube. Although in appearance not so neat as when an internal liner is used, there is the certainty of being able properly to fix the sleeve in position. Photograph Fig. 12 shows a drilled tube 1in. by 20-gauge reinforced by a sleeve (in halves) 2½ins. long by 18-gauge thick, pressed into position over the hole. This tube was subjected to an alternating stress test at 400 revolutions per minute. The sleeve expanded at the ends under the test and gradually became so " bell-mouthed " as to be of little practical use. The tube fractured across the hole at 9,320 revolutions.

Photograph Fig. 13 shows a tube cut from the same length and similar in all respects, but it had the sleeve soldered in position. This tube did not break until after 43,867 revolutions had been made, and then it failed between the sleeve and the grips.

Another piece of tubing, also from the same length, having a plain hole drilled through and not reinforced at all, failed across the hole after 3,684 revolutions.

The following is a tabulation of the results just described :—

Sleeve pressed on only	9,320 revs.
Sleeve soldered on	43,867 ,,
Without sleeve	3,684 ,,

These tests point to the fact that a sleeve merely pressed into position has little value, but that when fixed to the tube by soldering or similar means it acts as an efficient reinforcement.

Fig. 14 shows three types of reinforced tubes. No. 1 is formed by drawing a round tube over two " D " section tubes. The tubes are firmly fixed together by drawing, but are not brazed or soldered. These combinations were designed to take the place of butted tubes in motor-cycle frames, which were failing through excessive vibration. Tests made on a shock-testing machine proved that this form of tubing had a much longer life under shock and vibration than plain tubing of the same weight. When a fracture occurred under test, which was always after a greater number of blows than the plain tube would sustain, it was only the outer member that was affected, the two " D " tubes being quite sound.

No. 2 is a triangular reinforcement formed by drawing an outer tube over three other tubes of the shape indicated in the sketch.

No. 3 has a cruciform reinforcement formed by four inner tubes.

A number of tests were carried out at the time on laminated tubes, formed by drawing one light tube over another, to take the place of a tube of the same weight as the two combined. Under the few tests made the laminated tubes withstood vibration and shock much better than the plain heavy-gauge tube. The only reason we can assign for this is that cold drawing hardens the outside of the walls of the tube more than the centre if the tube is a thick one, and by drawing together the two thin tubes to give the same thickness of wall the metal has the benefit of the double drawing operation. Further tests are necessary to prove or disprove this point.

Tube Manipulation.

The possibilities of tube manipulation such as butting, tapering, drawing with taper gauge, expanding, flanging, bending, lapping, etc., are becoming better understood. Some designers, however, whilst recognising the usefulness of these different operations, still ask for what is not commercially possible, because they fail to make allowances for the alteration in the thickness of the

tube which will occur as the result of such operations. For instance, if the diameter of a tube is increased the thickness of the wall is reduced, and if decreased in diameter the thickness is increased. Again, if a tube is flanged, the flange will not be of uniform gauge, but will decrease in thickness as it increases in diameter. Photographs Figs. 15 and 16 will illustrate these points.

Photograph Fig. 17 shows a section of a bent tube cut from an F.2.B. undercarriage " V " strut. The gauge of the tube has, by bending, been reduced on the outside of the curve from .061in. to .048in., and increased on the inside from .061in. to .072in. The thinning of the tube would cause it to break if it had not been properly annealed; and further, if proper mandrils had not been used, or the tubes had not been filled with suitable material, a series of " puckers " or " corrugations " would have been formed on the inside of the bend. Where proper thickening up of the wall along the inner curve takes place in bending the bent portion of the tube is the strongest, but if " puckering " takes place this point becomes the weakest.

Bending is sometimes carried out on steel tubes whilst in the hot state, but where strength is required this is bad practice, as by heating the tube is rendered much weaker than it would be if bent in the cold state. Photograph Fig. 18 shows two " V " struts, one bent in the hot and the other in the cold state. The same weight was applied in each case, but it will be seen that the tube bent while hot has been distorted much more than the other.

A few illustrations of bent articles will be given towards the close of this paper.

Tubular Joints in Aircraft Construction.

Generally speaking, structural work for aircraft purposes is to-day carried out by means of sockets placed in suitable positions and arranged to receive the ends of the various tubular cross-members and bracings. These tubes and sockets are connected in three or four ways, namely :—

By brazing.
By silver-soldering.
By soft-soldering.

Sometimes the sockets or lugs are dispensed with, in which case the cross-tubes are mitred and welded direct to the main tube.

The latter method is not advisable except in very rare instances, as any operation involving great heat is dangerous, owing to the weakening which results from the annealing or perhaps burning of the steel.

Another method is sometimes employed in which the cross-bracings are connected by means of a hinge joint to a sleeve on the main tube, as in " D," Fig. 19.

This illustration shows four types of lugs used in aircraft structural work. Of these, " A " is perhaps the more common, the lug being made up by one long sleeve, with two branches mitred and welded on. Into and through these the main and branch members are fitted, and are held there, preferably, by soft-soldering and pegging. " B " shows another form of lug, this being made in two halves, pressed to shape, trimmed to depth, and welded along the joints. A wiring key will also be noticed. " C " shows a three-way lug, with double wiring key, while " D " is arranged for the hinge cross-member.

Photograph Fig. 20 shows some of the tests carried out on these lugs.

It will be useful to give the results of some comparative tests made on these various methods of jointing tubular structures, but before doing so we would remark that, in a paper like this, only the fringe of the subject can be touched. Everyone who is in any way connected with the practical side of aeronautical

construction will readily call to mind many other types of joints, each designed for a special purpose or to overcome a constructional difficulty.

Speaking from an experience of at least eight years, in which we have been in touch with aircraft construction and design, we have met with a surprising amount of fluctuation in the respective popularity of soldering, brazing, welding, etc., for steel tube work, all these methods having been ruled out in turn, only again to find favour in certain quarters. This is partly due to the fact that machines designed by private manufacturers have been brought into great popularity, and the methods and designs of such makers adopted.

We have seen welding carried almost to excess and then almost abolished. Brazing has been boomed and then decried, and soft-soldering substituted for it —with a different type of lug or joint to allow for the rescued strength of the flux. This again has been deemed unsafe, and silver-soldering, or hard-soldering, has risen into prominence, and to-day one hardly knows which type really is the popular one, as on the machines now being built for war purposes all styles and types of jointing may be found.

One has to realise that in all these methods the human element comes much into play. For instance, it is possible so to weld a joint that it appears to be sound, yet it may be a " fake "—metal being merely laid on and not fused with the surrounding parts. Or again, the welded joint may be burnt, thus causing a dangerous weakening.

Similarly with brazing, it is possible with care to make a fine type of joint, but the probability is that in a certain percentage of cases overheating will take place and failure result.

We will now deal with the results of a few experiments recently carried out on certain of these types of joints.

Soft-Soldered Joints.

Let us take soft-soldering first. In all cases the tests were made with a soft-solder composed of 60 per cent. tin and 40 per cent. lead—using " Fluxite " or some similar article as a flux.

Tubes of various gauges were tried, but up to a certain point the strength of the soldered joint was such that the tube failed in tension without the joint giving way. The following table (Fig. 21) gives the results :—

It will be seen from the above that the strength of a soldered joint is much greater than it is generally supposed to be, and from experiments carried out, the clearance or thickness of the soldering material does not, between the limits of .001in. and .008in., make much difference, but for any components that can be guaranteed to size we would recommend as " thin " a joint as possible.

A striking example of a strong joint of the type just referred to is given at Fig. 22. The test on this joint was carried out in order to prove to the satisfaction of inspectors that the stipulated minimum clearance of .005in. on the diameter was not necessary. In this particular case the elevator lever was held stationary while a torsional load was exerted on the tube. The result speaks for itself. The method of testing is shown at Fig. 23.

One of the chief arguments against the use of soft solder is the reduction in strength resulting from vibration, it being claimed that this form of joint will not sustain a vibratory load nor a series of shocks. This may sometimes be right, but even under these conditions a very satisfactory result can be obtained if the sweating is done thoroughly and well, and added strength is given if the joint be " pegged."

Tests on Soldered Joints.

The writers recently carried out some experiments on what may be termed a "Tup-testing machine" for soldered and brazed joints. This machine is illustrated by Fig. 24. It will be noted that the rising and falling tup is actuated by a bell crank lever, worked by a "sudden-drop" cam rotating in the direction of the arrow. The dead load on the tup shaft can be varied by means of the sliding weight.

A standard drop of 4ins. was arranged for, and the method of making the test piece is shown by the enlarged section.

It was at first thought that the effect of the "tup" action would be to quickly rupture the joint, but to our great surprise the joint held to such an extent that we found it necessary during the test to increase the load from 10lbs. to 24lbs. The following are the details of the test:—

Size of tube: 1in. o/d. by 18-gauge.
Depth in socket (or lap): ½in.
Thickness of solder: .005in.
Number of blows: 113,500 with 10lb. weight tup.
Further number of blows: 64,000 with 24lb. weight tup.

At this stage the joint showed signs of giving way, so it was decided to apply a tensile test to see if the repeated blows had in any way deteriorated the solder. To our surprise the tube did not pull out until a load of 5.2 tons had been registered, giving the excellent result of 3.31 tons per super inch on the solder lining.

As regards the general results of soldering, the following list of tests (Fig. 25) will give a good idea of the strength attainable under proper care and supervision.

It may be urged that these results are not a fair basis on which to reckon, as they do not represent the ordinary work of the average operative. In answer, we would say that these results were all obtained from test pieces sweated by different operatives, in some cases being the work of girls with about two months' experience.

It may be possible to work out a formula to arrive at a basis for designers of soft-soldered joints, but even here, as in all calculations relating to structures, other factors have to be taken into account. For instance, a joint may be quite strong enough if in a 1in. by 20-gauge tubular joint the solder reaches to a distance of ½in., and working on this basis it follows that the same distance for a 2in. diameter tube of the same gauge would be correct, but no one would be satisfied with this, and would naturally double the length of socket to meet the increased diameter.

Generally speaking, it may be taken for granted that with ordinary care, and with a good quality of soft solder, a joint can always be made to withstand a shearing stress of 2½ tons per super inch on the solder itself—provided (and this is the crux of the whole matter) that the articles are well tinned and cleaned prior to the operation of sweating.

As regards the apparatus for sweating, different people will have a different choice, but having tried soldering irons, blow-lamps, coal-gas jets, and hydrogen flame, we have found that the three latter are about equal, and each is better than a soldering iron alone, but this latter is necessary for finishing in awkward corners. Eventually the use of a simple electrical device will probably become popular for repetition work.

Brazing.

As previously mentioned, this means of connection still has many adherents.

There is, however, a great disadvantage attached to it, viz., the risk of burning the tube owing to the intense heat necessary. That this burning and consequent weakening does take place can be easily shown by the results of tests carried out by us on a cantilever testing machine (Fig. 26).

The tests were upon tubes which had been fixed into sockets and brazed or soft-soldered. The following list (Fig. 27) shows the decided disadvantage of the brazed joint from the standpoint of strength :—

A further series of tests was carried out on the alternating stress machine, and these results are shown in list (Fig. 28).

Another point may be mentioned with regard to these tests. It will be seen that the result of Test No. 3 (soldered) is poor in comparison with the others. This joint is " faked," the tube and socket being left dirty and improperly tinned, in consequence of which the soldered joint had no " life." Even under these conditions the joint held for 75,130 revolutions, as against about 4,000 for the brazed joint. At this point the socket failed, due to the insecure fixing of the tube.

Another peculiar feature of this test was the heat generated in the brazed tubes due to the constant working of the molecules. The tubes commenced to warm up almost immediately, and before they broke the temperature of the tubes near to the points of fracture (*i.e.*, near the socket) was about 120 deg. C., sufficient to cause the charring of any adjacent wood, whereas the soldered tubes remained quite cool until the last few minutes prior to fracture.

We are quite aware that in many places on aircraft structures brazing is permissible and good, but where any weakening of a member is likely to cause disaster brazing should be carefully avoided.

Silver Soldering or Hard Soldering.

The foregoing remarks as to brazing hardly apply to silver-soldering, as by this method a strong joint can be obtained without undue heat. We are not in a position at the moment to give any comparative figures of tests, but we should say that, from the standpoint of tensile strength, silver-soldering is higher than soft-soldering, and very near to that of brazing. The heat necessary to perform the operation is lower than for brazing, and is not likely to weaken any members if reasonable care is used. It is, however, a longer process, and the material used is very costly.

Welding.

We may well ask curselves, in these days, where we should be without some form of autogenous welding. The thousand and one articles that are built up of sheet metal welded together speak for themselves, and make us wonder how we ever got on without this useful engineering process.

Still, welding has its limits of usefulness, and if exceeded danger may be near.

In the early days of aeronautical engineering welding was often used in places and on parts where to-day it is " taboo," and such a method as welding tube to tube has dropped to a great extent out of favour, having been superseded by the more costly but better and safer engineering practice of jointing by means of machined or built-up tubular sockets, previously referred to.

Welding—by whatever means it is done—is always open to a certain amount of doubt, and though there are innumerable cases where this doubt as to the strength of a joint is well covered for, yet, owing to the hidden nature of the

defects of welding and the possibility of burning and oxydisation, present-day designers avoid it in any important member of an aircraft structure.

A most important rule introduced during recent years has been the suitable annealing of welded joints, and this rule should be adhered to whenever possible. Many will have noticed the brittleness of a welded joint before annealing or normalising, and the malleability of the same afterwards.

On this point the writers have discovered within the last few months a rather strange fact. We had occasion recently to make up some small lugs—somewhat as shown at Fig. 30—from which it will be seen that a certain amount of shortening took place as the result of the welding on of the arm. We have since noticed this shortening in other tubes, some of quite considerable length, where various fittings have been welded on at intervals, and so far we have not arrived at a satisfactory explanation.

For the sake of any who may not have been able to carry out their own tests on welded joints, it may be helpful if we here give the results of some experiments we have made.

The easiest method of welding is the butt joint, *i.e.*, when two tubes are placed end to end and joined together to form one length or mitred together to form one piece. In such a case the surfaces to be welded are readily accessible, and the flame has freedom for doing its work.

A more difficult type of welding is that necessary when one tube has to be mitred to the outside of another tube, as when forming a " T " lug. In this case the easily-melted end of the one tube has to be united to the outside surface of the other, and anyone who has had experience with welding will know how much more difficult it is to attack the hard outside skin of a tube or sheet than it is the edge.

In order to prove this point we carried out tests on tubes measuring 1in. outside diameter by 20-gauge and 1in. outside diameter by 16-gauge—some being butt-welded and others having an interposed tube of about the same diameter, to which the end of each tube was welded.

Fig. 31 will show the method of building and also the results obtained.

Fig. 32 illustrates the test pieces after pulling.

Fig. 33 shows some rather fine crushing tests on welded joints; in both cases the test was taken as the result of an accident, but the samples thereby produced compensated in some measure for the loss otherwise sustained. No crack in the weld took place, even though the punishment was so severe.

Comparative tests were made on a cantilever tube joined to the main member by welding, and a similar type of loading was also tested for a lug, with the tube fixed in place by welding.

These are shown on Fig. 34, and the following were the results :—

Welded direct to tube	335lbs.
Welded into socket	365lbs.

An illustration of the joints after testing is shown in Fig. 35.

Welding is often harshly criticised as regards its ability to withstand vibration, but even in this respect we have found striking instances where the tube has broken before the joint.

Some time ago we tried an intermittent shock and vibratory test on a machine shown diagrammatically in Fig. 36. This machine gave a series of vibrations to the tube, the blows due to the " peg-cam " being 1,400 per minute. In some cases the tube broke off without the welded joint suffering in any appreciable manner. Samples of test pieces and the results are shown at Fig. 37.

As regards welding of any description to be done on tubing, we do not advocate the use of tubing made from steel too high in carbon. A low carbon steel gives the better result, and it is also most essential that the phosphorus content of both tube and welding wire shall be low.

Wherever possible, we would suggest that the welding on of hinges and sockets to a main spar or post be avoided. To slot a tube or soften it by welding is unwise, and in place of any fixtures that at present demand such operations we recommend a sweated and pegged fitting.

In support of this, Fig. 38 shows some experiments carried out by our Company, in order to convince some of our friends of the advisability of following the course we have suggested. In one case it will be seen that a wiring lug is fixed on a main spar by welding, and in the other by sweating and pegging. Alternating tests on these tubes gave the following results :—

Welded	...	...	...	...	...	5,190 revs.
Soldered	...	...	...	...	...	8,800 ,,

Tubular Construction Work.

A few illustrations of tubular constructional work with which we have had to deal during the last few years will probably be of interest.

Fig. 39 shows a streamline and tapered strut (seamless) which we produced prior to the war. This idea is now being carried further, and we quite expect that these will soon be generally adopted in lieu of wood.

Fig. 40 shows a large trussed girder as designed by us for use in experimental airship planes. This girder weighed (complete, as shown) $4\frac{3}{4}$lbs., and a load of 5cwt. at the centre of the 8ft. span produced a deflection of only $\frac{1}{4}$in. A similar girder, weighing $5\frac{1}{2}$lbs. with a depth of $7\frac{1}{4}$ins., buckled and collapsed at a total load in the centre of the beam of 10cwt., equal to one ton distributed evenly. The distance between supports was 8ft. 6ins.

Fig. 41 shows a triangular trussed girder or strut which has not yet been tested. The particulars, however, may be of interest :—

The length over all is 9ft.
The side of triangle 12ins.
Total weight, $9\frac{3}{4}$lbs.

The load that this will sustain will be found to be great in proportion to its own weight.

Fig. 42 shows a rather difficult example of bending and streamlining. This is in connection with an exhaust pipe for one of the earlier B.E. machines, and the design presented considerable difficulty when it came to be carried out.

Fig. 43 gives a sectional view of a tube 2ins. diameter by 18-gauge which has been expanded at one end and tapered and reduced at the other.

Figs. 44 and 45 show a patented method of tubular joint suitable for aircraft work. Design No. 1 is arranged for an intermediate joint for a tubular longeron or the like, while Design No. 1a deals with the method of connecting an end eye or connection lug.

It will be seen that this type of connection embodies the dual arrangement of internal and external sleeve, the former being slit. The two are connected and gripped on to the tube by means of the small screws shown.

Tests carried out on this form of joint have given, so far, excellent results.

Figs. 47 and 48 show various forms of tubular manipulation performed in dies and tools.

Fig. 49 shows a good example of cold bending of tubing of 1½in. diameter by 16-gauge thick.

Fig. 50 shows an aeroplane engine water pipe in seamless steel of a very light gauge; this, when well tinned, makes a very efficient substitute for copper piping in many cases, and has the further advantages of decreased weight and cost. The weight of the sample shown is 7ozs.; diameter of tubing 1½in.

Fig. 51 is of another aeroplane engine pipe, with very awkward twists and bends.

With Fig. 52 we return once more to the plain, seamless steel tube, and show some results of the crushing tests that good aircraft tubing should stand. Very strange shapes often result from this type of test.

Rust Prevention.

One further point remains to be mentioned. It is well known that a long life for any modern aeroplane is not expected. The present necessary wastage in aircraft is such that the question of internal rust and corrosion of the steel work is not of serious moment. The time is coming, however, when such matters will have to be seriously considered. For any post-war machines—especially if designed for general passenger traffic—the question of the length of life of all parts will be one of primary importance. Many experiments have been carried out in this country with this end in view, but nothing definite has been reached.

We have experimented with two or three methods of preserving from rust and corrosion, with fairly satisfactory results, and in the case of airship framework, subject as it is to salt-water influence, we have used with fair success the "cosletising" process.

For soldered work, such as rudder and fin frames, we have instituted at our Works a thorough system of washing and brushing in hot soda water to remove all traces of the fluxite or the flux, and we think this is most essential.

In conclusion, we would say that "the last word" in tubes and tubular structures has not by any means yet been spoken. With the increase in the size of machines, the constant and ever-increasing shortage of seasoned timber, the extended use of machines in future years in hot climates, with all the climatic effects on timber, the "all-steel" machine will undoubtedly soon become a reality and a necessity, and consequently the subject of tubes and tubular construction assumes increasing importance. We all have much to learn on this subject, and we trust that this paper will prove of mutual benefit, and help forward in some way the science of aeronautics and the good of the community at large.

[*We regret that owing to circumstances over which we have no control it has been found necessary to omit the illustrations to Mr. Hackett's paper.*—Ed.]

PROCEEDINGS.

NINTH MEETING, 53rd SESSION.

The Ninth Meeting of the Fifty-Third Session was held in the Theatre of the Royal Society of Arts, London, on Thursday, May 2nd, 1918, Lieutenant-Colonel R. K. Bagnall-Wild, R.E., occupying the chair.

The CHAIRMAN said the paper by Mr. W. W. Hackett and Mr. A. G. Hackett, which was to be read that evening, was a most interesting and rather a long one, so he would make no preamble, with one exception. It would probably be necessary to ask a good many of those present to tender their remarks in writing, as the lighting and train restrictions rendered it necessary to close down at 9.30.

Mr. W. W. HACKETT and Mr. A. G. HACKETT read their paper on "Tubing."

Captain PHILPOTT said the subject of the paper was one on which they wanted to know a good deal. He was extremely interested in Mr. Hackett's remarks about the nickel-chrome hardened tubes, which become brittle when subjected to pickling in acid. Did the authors get any explanation why that occurred? He had tried to trace the cause of that trouble, and made one or two tests, and it seemed likely that the trouble was due to hydrogen getting into the steel during the pickling process. In trying to get some evidence in support of some such proposition, a number of pieces of steel were inserted in hydrochloric acid, and afterwards the pieces of steel were boiled in water, above which gas collected which exploded when flame was applied to it. Had the authors tried to solve the question why nickel-chrome steel was rendered brittle by pickling? With regard to the double tube—one tube inside the other—which was tested, he believed it was a fatigue test, *i.e.*, the rotary Wöhler test. It looked as though the test piece might act similarly to carriage springs, which were subjected to an alternation of stresses during their life and lasted a long time. Before feeling that that was satisfactory, he would like to see how the stress was calculated. It was not easy to calculate the stress of one tube inside another when it was subjected to a bending operation. An assumption must be made of the pressures between one tube and the other. He would have felt happier in discussing the other tests if he had seen the results beforehand.

Captain SMITH said Mr. Hackett suggested that the reduction of mild steel tubes was about 1½ gauges per draw, and the reduction of the nickel-chrome steel about half that. The difference in gauge varied as the actual gauge thickness. Was that reduction considered as an average value, or was that taken irrespective of the gauge to be reduced? The figures of the alternating stress tests appeared to show that there was a small amount of torsional breakage. It appeared to him that there was a certain amount of torsional stress set up during the revolution of the specimen, which might be due to a certain amount of lag of the load. He thought Mr. Hackett suggested that the cold drawing hardened the outside more than the inside of the tube. He thought that had been well shown in connection with the cold drawing of a mild steel bar. An important point which was clearly shown was the fact of the distinction between the brazed and the soft-soldered joints. Those experiments were worth while developing, and if the results arrived at with them were true, it was a big point which should be watched.

Mr. C. W. MEREDITH said the difficulty in using soft-soldered joints was that the outside diameter of the tube was not uniform, and consequently in practice it was very difficult to get the .005in. thickness of solder, on which the experiments

had been carried out. In cases where good fits could be guaranteed, soft solder was undoubtedly the better, but it would be dangerous to generally abandon brazing until further experiments had been carried out to compare the relative strength of brazed and soldered joints with different thicknesses of jointing material.

Tubing which was not truly circular was often supplied, so that in cases where this fitted into machined forgings, a uniform thickness of jointing material could not be obtained, and if the tube—as is frequently the case—was also undersized in the "mean" outside diameter, a considerably greater thickness of jointing material than .005in. was obtained, and for this reason his experience had been such that it would be advisable to braze in these cases.

Second Lieutenant W. R. D. SHAW said a point of interest in connection with tubes was that more care should be given to the selection of material. While two materials might give exactly identical strength-over-weight values, one material might be denser than the other, in which case the discerning engineer would employ the denser material rather than the lighter, because it would have a smaller detrimental surface and take up less room.

Mr. HAROLD SMITH said that some time ago he had occasion to suggest, in connection with aeroplane undercarriages, the employment of tubular V-struts of streamline section which were bent so that the lower parts, say a foot from the bend, were disposed in vertical planes instead of using the ordinary inclined V-struts which are straight from the fuselage to the axle support or seat. The bending of the streamline tubes, or struts, he was given to understand, presented certain difficulties in manufacture, and he would be glad to have the authors' views regarding this point.

Mr. G. I. PRICE said he was very interested in the samples of bent tubes shown. Could the authors give any information concerning the right means of determining the line that existed between the inner and outer radius of a bent tube that did not change in length during the bending process? The thickening of the inside of the bend was presumably equal to the thinning of the outside. He believed that sort of thing was generally left to the practical operators in the shops, but it seemed to him that it must be possible to determine the position of that neutral axis. Was there a right method of doing so?

The CHAIRMAN said the authors gave one analysis for nickel-chrome steel, but did not give any details as to the care and trouble taken in altering the annealing temperatures to meet the various analyses. No details were given as to the temperatures and times in the heat treatment. The question of suitable filling for bending was mentioned. It would be very valuable, especially for aircraft constructors, to have details in regard to that, because they often attempted to bend the tubes themselves, and they did not always succeed. He asked both these questions for the benefit of the user, rather than from the manufacturer's point of view. One thing that struck him very much was the ingenuity and the multiplicity of the testing machines that had been used, and the amount of "meat"—if he might use the expression—in the test results obtained was something colossal. He knew what it meant to produce such an enormous number of figures as had been produced by the authors, who had given a large number of comparative tests of tubes, and tubes in fittings. He would like to know whether those tests were made with pieces of tube all cut off the same length, or lengths of tube all made at the same time, with the same analysis, and so forth? No doubt the figures were valuable, but he would like to see some of those tests correlated with analysis figures and with the usual test results that were included in the ordinary specifications. With regard to welding, he was glad such strong expressions of opinion had been put forward by the authors on that subject, as it was one of the most difficult they had to face. He always had cold feet when he had to look at a weld. Had the authors had any special difficulty in regard

to welding, and what precautions did they take with alloy steels? They mentioned that low-carbon steel tube and plate was preferable. He would like to know their experience with high-nickels, high-chrome, low-nickel, medium-nickel-chrome and medium-carbons.

In reply to the discussion,

Mr. W. W. HACKETT said in reference to Captain Philpott's remarks regarding the effect of the pickling on chrome-nickel tubes that had been hardened, his explanation coincided with theirs (the authors). He asked everyone to avoid it. That was what they were out to warn people against. Captain Philpott also asked, in regard to laminated tubes, how the stresses were worked out. They took the strength of two tubes .032in. thick, which was equal to one tube of .064in. They took one tube of .032in. thick and drew it down to another of .032in. thick, and tested it against a tube of .064in. He thought that gave the same results as regarded its weight. Captain Smith asked how the reduction of gauge was reckoned. They went from 10 gauge to between 11 and 12 gauge in the particular case mentioned. The gauges came down roughly in steps as follows:—

22	gauges ...	...	.028in. thick.
21	,, ...	...	.032in. ,,
20	,, ...	...	.036in. ,,
19	,, ...	...	.040in. ,,

Then they jumped in eights:—

18	gauges ...	...	.048in. thick.
17	,, ...	...	.056in. ,,
16	,, ...	...	.064in. ,,
15	,, ...	...	.072in. ,,
14	,, ...	...	.080in. ,,

Then they jumped to twelves and sixteens, and by that method one did not get far wrong. It was a fairly good rule to give a gauge and a half per draw to ordinary mild steel tubes and half that to chrome-nickel tubes. It might be thought that as chrome-nickel tube was stronger, it should be able to stand the same reduction as mild steel, but they had had a lot of trouble through trying that theory. Someone said in regard to soft-soldering, there was a variation of 1/64in. in the size of the tubes. There should not be. All his company was expected to allow was a plus of .004in. If they were to get 1/64in. variation it would be too much, and he would certainly complain. A question was asked about the length of tube that was going to be bent. By measuring round the neutral axis—the middle of the tube—one practically got the length taken for bending. In the illustration he gave of the bent tube, he gave figures which he thought showed that it had thinned on the one side practically as much as it had thickened on the other side. By going right round the middle of the tube to find out the amount required one did not get far wrong. Lieutenant-Colonel Bagnall-Wild asked about the annealing temperatures. For mild steel the temperature to avoid was about 650° C. to 750° C. It was best either to go above those temperatures or to keep under them in the working. The safest way, as a rule, was to keep under. They got a more uniform result if a temperature of about 850° C. was got by close annealing before the last drawing operation. With regard to the blueing of the finished tubes, this was done at temperatures of between 380° C. and 450° C. The period must be according to the thickness of the tube. Take 18 gauge—about normal thickness—that was given about 25 minutes, 10 gauge 40 to 45 minutes, and 20 gauge 15 to 20 minutes. Various materials were used for filling before bending. Lead was one, and resin another, but resin should always be used in a fireproof building. It was one of the easiest and cheapest things to bend with, but there would be trouble unless it were done in a proper building. If filling were not used a special mandrel must be made,

which was very expensive. The test pieces described were on every occasion taken off the same piece of tube. They (the authors) had not set out to prove a theory, but to let the test pieces prove the case. A length of tube was cut up and the tests were taken in a fair and reliable way. If anyone would like the tests carried out again, it might be worth while, and they were quite willing to go on and take any test that members of the Society wished. With regard to the tensile testing, each batch of tubes had a number of tests carried out by means of tensile testing, flattening and crushing. The crushing tests used were some of those taken from the Aircraft Inspection Department. With the heat treatment given at their works they got not more than a half per cent. of rejections from any causes. He thought the correlation of their tests with the tensile tests one got in the normal work was given in some of the charts. On all the charts the tensile tests and elongation were given.

Mr. A. G. HACKETT said, in regard to Captain Smith's question, there was very little torsion effect on the alternating machines. When the machine was in operation the tube was practically in alignment with the machine spindle. If it were carried round by the torsion effort it would carry out of line. Sometimes it wobbled, and they had to rush to stop it. By putting the weights on too quickly and setting up vibration harm was apt to be done without proving anything. The case put forward by Mr. Harold Smith presented no difficulty. The bending of two pipes which had been shown on the screen, and which were streamline tube 2in. by 1in., or probably more, gave very little difficulty when proper tools were used. They had now in hand a 6in. by 2½in. tube, streamlined, to be bent on the flat. In ordering tubes for bends it was usual to allow a little over and cut to the right size after bending, otherwise one would not get the accuracy the A.I.D. expected. No doubt many of those present had found, as he had done, that in trying to bend annealed tubing, say 1 inch, 20 or 22 gauges, it puckered. It was better to bend it in a slightly harder condition and anneal it down afterwards. It was impossible to bend it properly if it had been annealed too far. That point should be brought more in front of contractors who had to deal with tubular bends. With regard to the point raised by the Chairman as to filling for bending, with a close-wound spring of suitable strength a small bend could be got, and to avoid any chance of buckling or breaking the spring could be twisted in and twisted out again, and good results could be obtained, but for anything past a certain angle it was not a practical proposition.

Dr. HATFIELD (Sheffield) wrote that he much regretted his inability to be present at the reading of the paper. It was a subject in which he was much interested and he was sure the Society was much indebted to Messrs. Hackett for the trouble they had been at in presenting such a detailed paper on "Tubes." He was particularly interested in the authors' comments upon air hardening nickel-chrome tubes and quite agreed that there was much scope for this class of material. Had the authors attempted to produce stainless steel tubes, *i.e.*, tubes from the 14 per cent. chrome steel which was now being produced in considerable quantities? If the authors had had any experience with that steel he would be glad to read any comments upon the subject which they cared to make.

He was interested in their observations upon tube manipulation, particularly in their remarks to the effect that cold bending was more satisfactory procedure than hot bending. He ventured to suggest that considerable care should be utilised in applying this deduction. In his (Dr. Hatfield's) opinion there was always danger in cold bending since it resulted in local deformation of the material. It is quite easy to conceive that such cold work might be evenly distributed under certain conditions, but such bending was apt to produce exaggerated local deformation likely to make parts unsafe. With regard to soldering, brazing and welding, he felt that whichever process was used, considerable care should be employed, and he must confess that he, personally, was not in love with either of these procedures. In soldering, the temperature effect upon the steel in

certain cases might be serious, whilst as regards welding he had in his paper before the Society illustrated some of the serious disadvantages of that method. No doubt, however, the aero engineer had to make the best use of the methods available.

Unfortunately, in going through the paper, he was at a disadvantage owing to the absence of the illustrations, but would like to conclude by again expressing his appreciation of the work.

There was very little literature extant upon the production and properties of steel tubes and he was sure we were much indebted to the authors.

The CHAIRMAN moved a hearty vote of thanks to the authors, and he asked members to write some remarks on the paper, as they seemed rather shy of putting forward their remarks in a hurry. Let them have more discussion—especially from the point of view of the use of the tubing in the works—on the use and abuse of the tubing.

The motion having been carried,

Mr. W. W. HACKETT acknowledged the compliment, and said he and his brother were pleased to give what help they could in solving some of the problems the trade had before it. If there had been no criticism they would have felt that their time was wasted. They would be pleased at any time to go further into any tubular problems for any of the members. The question of the effect of extreme cold on tubes in different conditions should be taken up. He would have made tests before now but for the difficulty of getting tubes sufficiently frozen. He knew cold had a bad effect on iron and steel, and the high altitude at which aviators flew and the low temperatures they met with made the matter of particular interest to them.

A vote of thanks to the Chairman, moved by Mr. HANDLEY-PAGE, closed the proceedings.

THE LIBERTY ENGINE.

BY COKER F. CLARKSON, GENERAL MANAGER OF THE SOCIETY OF AUTOMOTIVE ENGINEERS OF THE UNITED STATES OF AMERICA.

The automotive engineers have had a most important part in the conduct of the Government aircraft programme. It is well known that the development of the Liberty Engine is properly credited to engineers who are members of the Society of Automative Engineers and whose work has been greatly facilitated by the present and past activities of the society. Due credit must of course be given to the Allied Governments for data furnished to our engineers who designed the Liberty Engine, but it should not be forgotten that this engine is strictly an American product, having been designed for rapid production, standardisation and interchangeability of parts, factors not realised to the same extent in other designs. The benefit which this will have in increasing the effectiveness of our fighting contingents at the front can scarcely be over-estimated. The aviation engine is of course a high-strung piece of apparatus, one that must develop great power with minimum weight. The engine operates under full load and at high temperature practically all the time, so that its depreciation is relatively rapid. This in turn greatly increases the service problem and new parts must be supplied frequently in order to keep the maximum number of machines in operation. Here again we realise the importance of standardisation and the necessity for absolute interchangeability, factors long appreciated by automotive engineers and practised especially in the automobile industry in this country. The society is justly proud

of the work its members have done in connection with the production, inspection and upkeep of aeronautic apparatus. There is no more important work that they can do. In addition, the possibilities for development in the aeronautical field following the war are almost unlimited. A careful study is being made in connection with the National Advisory Committee for Aeronautics looking to the developing of a practical type of airplane for carrying mails, and the details are being worked out for the establishment of a number of airplane routes between several of the commercial centres, to be put into operation as speedily as satisfactory machines can be obtained for the purpose.

THE COMPUTATION OF AERODYNAMIC SUPPORT.

BY W. R. D. SHAW.

(*Exclusive to the* AËRONAUTICAL JOURNAL.)

For Aerofoils of Circular Arc Camber.

The function of an aerofoil of circular arc camber is to impart motion in a circular path to a mass of air whose volume is determined by the product of span, chord, and mean sweep, the latter being a linear measure of the depth of the strata of air affected above and below the surface.

Notation Employed.

Total pressure on aerofoil, lbs. wt.	P
Flight velocity, feet per second	V
Chord dimension, feet	y
Maximum camber, feet	c
Radius of curvature, feet	r
Span, feet	m
Mean sweep, feet	d
Density of air, lbs. per cubic foot	ρ
Acceleration due to gravity, feet per sec. per sec.	g

By the Theorem of Pythagoras

$$r = \frac{y^2 + 4c^2}{8c} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

In practice the sweep factor or mean sweep varies from 0.8 to 1.2 times the chord dimension. Taking the average value

$$d = y \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The volume of air continually in dynamic contact with the aerofoil is in cubic feet from (2)

$$my^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

The weight of the volume of air (3) in pounds is

$$\rho my^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Taking ρ as .08 lbs. per cu. ft. and g as 32.2 ft. per sec. per sec., the total air pressure, which in effect is the centrifugal reaction of the air on the curvilinear surface, is given by the expression

$$P = \frac{.0194\, my^2 V^2 c}{y^2 + 4c^2} \quad . \quad . \quad . \quad . \quad . \quad (5)$$

REVIEWS.

Aviation Engines. By Lieutenant Victor Page, A.S.S.C., U.S.A.

Several text books of this description have been published during recent months, all of them covering practically the same ground, and, owing to the restrictions necessarily imposed by the present abnormal conditions, and by the very rapid advance in aero engine development, being of limited value in the presentation of current engine construction, and from the point of view of those intimately connected with the design, construction, or handling of these engines, the instructions given in these books are always bound to be more or less behind the times.

It is considered that this effect is greater than it need be. Owing to the rapid development of the engines and the time required to publish these books after the censoring of the first proofs, it would be probably safe to say that if the book was written around modern engines and not censored at all, the information given would not be of any great value to the enemy by the time the book was published.

In connection with the above it is noted that the most modern engine of European design described in this book is the 150 h.p. Hispano Suiza Model A, which engine was in use on the Western Front as long ago as the early part of 1916.

Probably in consequence of the above, the greater part of this book consists of simple explanations of the various laws governing the action and design of an internal combustion engine, and of general hints on adjustments and repairs. These have been obtained by extracting the data from various sources and re-writing in a very clear manner, and also by simple graphic illustrations which will convey very clearly to the mind of the non-technical reader the meaning of the text.

The range covered by this book is very comprehensive, and it is not possible to deal *in extenso* with the contents, but Chapter IV., dealing with the reasons for, and the sequence of, operations on a multi-cylinder engine is very direct in its text and provided with simple graphic illustrations.

Chapter V., on carburettors, provides a very complete series of illustrations and descriptions of most of the types of carburettors in use at the present moment, and also deals with the evolution of the modern carburettor and the use of many details which, to the uninitiated, appear to be superfluous.

The curve given in p. 144 showing change of air density with altitude is only approximately correct, but serves to illustrate the text.

It would be of value if the description of the effect of altitude on carburation had been more complete; as it stands it will leave an impression on the mind of the reader that the trouble is caused by " not enough air reaching the mixture " (these are the author's words), whereas it is due to the different effect of the change of altitude (*i.e.*, density) on the comparative flow of the air and of the petrol.

The weight of air passing through the carburettor varies approximately directly with the density, but the velocity remains constant; the flow of petrol through the jet will vary as the square root of the density difference, *i.e.*, at an altitude of 10,000 feet the standard air density is 74 per cent. of that at sea level, and the weight of air and the B.H.P. of the engine will vary

accordingly, whereas the quantity of petrol flowing through the jet will be 86 per cent. and the explosive mixture will therefore be 1.165 times stronger than it was at sea level, this representing a waste of petrol of approximately 16 per cent., and affecting more or less seriously the running of the engine.

Chapter VI., on ignition, is very complete, the chief value of this, on this side, being the complete description of the "Dixie" magneto, which is now in fairly common use on English made engines.

The author's remarks at the end of Chapter VII., on air-cooled engines, are evidently based on the results obtained on now obsolete designs of engines. Modern air-cooled engines can equal the performance of the average water-cooled engines, and have the considerable advantages of decreased weight and vulnerability, and are more adaptable to aircraft requirements.

The chapter dealing with the use of various tools will be of assistance to the semi-trained mechanics, and the complete list of tools supplied with the Curtis O × 2 engines, and illustrated on p. 409, will most certainly set them longing a little, as it is on this point that the English make of engines most signally fail. The mechanic is given a delicate engine to handle, and is not usually supplied with the special tools required to do the work efficiently and expeditiously.

The Author in his preface remarks that the book is prepared primarily for instruction purposes and adapted for men in the U.S.A. Aviation Section. This necessarily means that the bulk of the illustrations and descriptions of processes apply to American designs of engines, the great majority of which are unknown in the English Flying Service.

However, the book is of value to any student or mechanic interested in the handling of aero engines, owing to the completeness and lucidity with which the general laws are explained.

J. S. IRVING.

Aircraft in War and Commerce. By W. H. Berry. 1918. London: E. J. Burrow. 150 pp. oct. 1s. 6d.

As Lord Montagu of Beaulieu observes in the introduction to this volume, there is something to be said for the airship as we'l as for the aeroplane, and in spite of the victory of the aeroplane over its bigger rival in the present war, there is still the interesting question as to whether it will be equally triumphant when the ploughshare succeeds the sword. Whether this question has been already answered or not remains to be seen. Mr. Berry has produced a highly interesting book of the popular sort. Like most of us to-day, he devotes the bulk of his space to the aeroplane, but his book is brimful of information, well i'lustrated and systematically arranged.

The Hoffman Manufacturing Company, Ltd., of Chelmsford, enclose a series of decimal conversion tables which are conveniently stated in handy form.

CORRESPONDENCE.

To the Editor of the AËRONAUTICAL JOURNAL.

DEAR SIR,—Since Mr. Riach has said nothing nasty about my "Resistance of Air," I suppose I may consider his review as not unflattering.

That the book is controversial is exactly what it was intended to be. It is not a "text book" in the ordinary sense, which is "too often a book whose sole purpose is to enable more or less stupid youths to pose as graduates of a course of mathematics." My little book is of no use to any student whose sole desire is to *pass an examination*. My object is to make the student *think for himself*, whilst the examiner's object is make him think *exactly as he does himself*. Since Mr. Riach admits that it has made him think, the book has, to this extent, succeeded in its object.

Where I join issue with Mr. Riach, however, is where he says that "much of the argument is based on *experimental work*, . . . yet it would appear that such fundamental questions . . . *should be finally settled rather by modern hydrodynamical theory than by any set of experimental results, however complete.*"

Experiment is, *in essence*, a question put to Nature; and Nature never lies. You may not understand the reply—but that is your fault for not having put your question properly. I think it was Professor Armstrong who said that before anyone performed an experiment he should have clearly in his mind *what he wanted to know*, and further, *what sort of a reply he expected to get*.

If hydrodynamics, or aerodynamics, is not based on experiment, what on earth is it based on? Mr. Riach would appear to reply, "on theory," or on hypothesis—? on imagination. But a theory might be popularly described as a scientific cabinet, with pigeon-holes in it, for *containing the facts*, which facts are carefully indexed. As long as the pigeon-holes will admit *all* the facts, the theory may be useful—since science is, *in essence*, "economy of thought." If facts are discovered which *will not fit* in any of the pigeon-holes—*disagreeable facts*—it will be necessary to look out for another cabinet, or "theory," which will hold them.

However, Mr. Riach appeals to Cæsar—to "modern hydrodynamical theory." What is this theory? And how far can we trust that its foundations are reliable?

I suppose that we may say the theory is, chiefly, a vast accumulation of differential equations, concerning the supposed motion of an imaginary fluid, which has some self-contradictory properties. Sometimes the theory agrees with experiment; but equally often it disagrees—sometimes very violently.

If a theory is to be of any use we ought to be able to predict (very fairly) by means of deductions from it. If we ask the theory the following questions, what sort of a reply are we likely to get from it?

1. How do birds sail (or soar)?

2. How are we to calculate the resistance of a spherical shot, moving at any given velocity, in air, or water?

3. What is the *Law* of the Resistance of bodies, moving in air, at a speed of 1,000 met. sec.?

(1) Mr. Mattock says it varies *as the velocity*, or, let us say, as $C.10^3$.

(2) The theory I support, says that it is as the *square of the velocity*, or $C.10^6$.

(3) Many authors say that it is as the *cube of the velocity*, or $C.10^9$.

(4) M. Honoré ("l'Illustration"), in his article on the new German gun, says that it varies as *the fourth power of the velocity*, or $C.10^{12}$.

Which is right?—or the most accurate? They may all be wrong; but they are, certainly, *not all right*.

4. How does a fluid move when passing out through a circular hole in a thin wall of a tank?

5. Why do all liquids and fluids move in spirals—say, for example, tea flowing out of a teapot, or the ascending smoke of a cigarette in *very still air*? Mathematically, they *ought* to move quite differently.

6. Why cannot theory show what is the fault of all propellers? If it can, why is their *efficiency* so very low?

I might add considerably to this list, but I will only point out, in conclusion, that it is not *very many years* since "theory"—or, more accurately, the High Priests of the Cult—were inclined to class all those who thought men would ever fly as little better than lunatics.

R. DE VILLAMIL.

May 1st, 1918.

RECENT ADDITIONS TO THE LIBRARY.

"An Aerial Race between a Briton and a German." (Originally published in 1751.) London. 1918. The Chiswick Press. Illustrated. For Private Circulation.

"The Problem of Flight." By Herbert Chatley, B.Sc. London. 1910. Chas. Griffin and Co. Illustrated.

"Flight Velocity." By Arnold Samuelson. 1906. Hamburg: Boysen and Maasch.

"The Aviation Pocket Book for 1918." By R. Borlase Mathews. London. 1918. Crosby, Lockwood and Son. Illustrated. Oct. pp. 362. 6s.

"Steels." Sheffield. 1918. Burys and Co. 29 pp.

"Aviation Maps, Aerodrome to Aerodrome." Designed by E. Hollocombe Clift. London: G. Phillips and Son. 1918. Eight miles to the inch. 12s.

"The Royal Naval Air Service." Harold Rosher. Introduction by Arnold Bennet. 1916. London: Chatto and Windus. 3s. 6d.

"Flying, Some of its Mysteries." V. E. Johnson, M.A. 1918. London: Henry Frowd. Oct. pp. 138. 2s. 3d.

"Elementary Aeronautics." A. P. Thurston, D.Sc. 1911. London: Whittaker and Co. Oct. 126 pp. 4s.

"Theory and Design of Structures." Ewart S. Andrews, B.Sc. 1918. London: Chapman and Hall. Oct. 620 pp. 15s.

"Flying: Some Practical Experiences." Gustav Hamel and C. C. Turner. 1914. London: Longmans, Green and Co. Oct. 341 pp. Illust. 12s. 6d.

"Structure of the Atmosphere in Clear Weather." By C. J. P. Cave, M.A. Cambridge University Press. 1912. 4to. Illus. 142 pp.

ABSTRACTS.

AERONAUTICAL ENGINEERING.

Aeroplane Engine Design.

This is a comprehensive review of recent developments in design and modern practice in regard to constructional methods and materials. The aeroplane engine is passing from the stage of invention to that of design. It is a light structure of high tensile steel parts, including seamless tubing, forged and welded parts. Certain components, such as the piston, exhaust valve, and guides, are designed for heat flow rather than mechanical stresses, and certain other components, such as the ports and crank-case, may be of any convenient material.

In order to secure low engine weight per horse-power, the mean effective pressure and the engine speed should both be as high as possible. For long flights, the weight of fuel and lubricating oil is a more serious consideration than the weight of the engine. The engine weight may be 4 or 5 lb. per h.p., and the weight of fuel and oil may be ½ lb. per h.p.-hr. The standard type of engine is now the water-cooled, four-stroke, fixed cylinder type with 6 or 8 cylinders in line, or 8, 12, or 16 cylinders in V-setting. The weight of metal in a water-cooled engine is about 1½ times that in an air-cooled engine, but the fuel consumption is about twice as great in the latter type owing to the lower compression permissible in the hotter cylinders. There is room for much improvement in the design of carburettors which will yield a dry, homogeneous gas mixture under accurate control.

The rate of flame propagation with reference to piston speed is an important factor at the piston speeds now used. Combustion is hastened by central ignition or by multiple ignition. An air meter must be used to determine the cam forms and valve timing producing highest mean effective pressure at high speeds.

The cylinder arrangement does not affect the weight of cylinder, piston, and connecting rod. Frame and shaft weight per cylinder is reduced by multiplication of cylinders, and circumferential multiplication is lighter than longitudinal multiplication. Only V-engines and engines with cylinders in line are now used; in the latter type, the weight per cylinder is reduced by using up to 6 cylinders in line. Large cylinder diameter and short stroke favour light construction.

Various cylinder constructions are reviewed, and their merits are discussed. The cylinders of the Hispano-Swiss engine are threaded externally and screwed into a double-walled aluminium casting, which contains the ports and water-jacket. Single-piece steel forgings with welded sheet metal jackets are satisfactory, but costly. The desirability of large valve-diameter influences the cylinder head design. Block arrangement of cylinders and jackets imposes undesirable restraint on the cylinders as regards thermal expansion and contraction.

The author deals with developments in pistons, valves, valve gears, frames, etc., and with the reasons for these developments. He makes also a thermal study of valves, pistons, and crank cases. (C. E. Lucke, "American Society of Mechanical Engineers Journal," May, 1917.)

The Cleveland Aero Engine.

The Cleveland aero engine is a decided departure from the usual design. It is of the horizontal "barrel" type, the axes of the cylinders being grouped round and parallel to the axis of the main drive. Each cylinder drives a single throw

crankshaft on which is a bevel pinion meshing with a large bevel wheel on the propeller shaft which rotates at half the speed of the crankshafts. The simplicity of this design enables most of the engine parts to be so standardised that they may be used in the assembly and repair of any size engine from 100 to 600 h.p.

The engine is of the four-stroke cycle type. Model 4, 150 h.p., has six cylinders 5in. by 6in., each provided with two inlet and two exhaust valves. The barrels of the cylinders are of steel tubing with water jackets and sparking plug bosses welded on. The combination cylinder head and manifold are an aluminium casting. The pistons are of aluminium alloy and have three rings each.

Ball bearings are used throughout and lubrication is secured by running oil on to the large bevel wheel which throws the oil about, thus lubricating other parts.

Ignition may be either by two magnetos, a magneto and a battery, or two batteries.

There is no crankcase casting proper, only a light sheet metal case being required. The design lends itself well to a streamlining of the aeroplane body. ("Aviation," New York, Feb. 15, 1918.)

The D.F.W. Biplane Brought Down During a Raid on Paris.

The German aeroplane which was forced to land during the night of Jan. 30-31, 1918, was a D.F.W. biplane of the well-known general utility type designated by the letter "C." The design of the machine is well-known to the Allies, as it appeared at the front during the spring of 1917.* What is of special interest is the fact that a machine of such a type took part in one of the recent raids on Paris, confirming the opinion that German raiding squadrons do not consist solely of large machines such as the "Gotha" or "Friedrichshafen," but include a few machines of the general utility type, which, besides acting as bombers, will be able to go to the aid of the slower and less easily manœuvred large machines.

The machine under discussion did not have its under-surface painted black, but it was "camouflaged," chiefly in brown and green. It has been noticed that while certain twin-engined machines captured earlier were painted black on their under-surface, others, captured more recently, were "camouflaged" in black, dark blue and light green. ("L'Aerophile," Feb. 1-15, 1918.)

The Location of Seaplane Floats.

A method of calculation for the location of seaplane floats is considered in some detail in this article, which is written by Mr. R. N. Wing, of the Curtis Aeroplane and Motor Corporation.

As the method adopted is the same whether single or twin floats are used, the special case of a single main float is considered in general by means of the following procedure:—

(1) A determination of the weight and C.G. of the machine with full load excepting the main float and float bracing.

(2) An estimation of the weight of the float and bracing, and the resulting full load weight of the complete machine.

(3) The design of the float for the required buoyancy and the calculation of an assumed 3° load water line and the centre of buoyancy line for the full-load weight.

* The above remarks are true so far as they relate to night bombing raids in France. It should be observed, however, that while the air endurance, with normal bomb load, is sufficient for an attack on Paris, it is barely sufficient for a raid on London, although an L.V.G., Type D11, made such a raid in daylight last year.

(4) A determination of the vertical position of the float with regard to the rest of the machine.

(5) A determination of the horizontal or fore and aft position of the float.

A typical numerical case is worked out for a seaplane, weighing 1,900 lb., with its centre of gravity located at a distance of 66ft.* aft of the face of the radiator, and 2in. above the line of the propeller axis. The propeller is assumed to have a diameter of 8ft. ("Aviation," New York, Mar. 1, 1918.)

The "Continental" Two-Seater Pusher Biplane.

This is a distinctly original design produced by the Continental Aircraft Corporation of New York City. It has a span of 36ft. and an overall length of 22ft. The lift loading is 7 lbs. per sq. ft., and the gliding angle about 1 in 9. The engine is a 110 h.p. Hall-Scott, model A.5, and drives a three-bladed airscrew.

The outriggers supporting the tail comprise two steel booms secured to triangular steel frames, covered with fabric, which replace the usual inner rear interplane struts. The booms are suitably trussed to the upper and lower wings. A monocoque construction is adopted for the nacelle, and the engine is mounted on heavy veneer panels slotted around the crankcase. A trapdoor allows the engine to be lowered to the ground when its removal is desired. The pilot, who occupies the rear seat, is provided with a starting crank.

There is an undercarriage with two skids and four Ackerman wheels, connected to the body by six streamlined struts. The wheels are mounted on rubber spring axles. Tusks are provided at the rear ends of the skids for use as brakes when landing.

This machine has covered 60 miles in 45 minutes (80 miles per hour) at an average height of 5,000ft. No information as to weights is given. ("Aviation," Feb. 1, 1918.)

The "Hannover" Biplane.

The "Hannover" aeroplane, which is made by the Hannoversche Wagon Fabrik, is a two-seater tractor biplane of new design which has recently been brought down at the Front.

The lower wings are smaller in span and chord than the upper wings, and their tips are more rounded. The upper wings are swept back at the tips in a manner reminiscent of the recent D.F.W. machine, and each wing carries a balanced aileron. The upper wings are supported by two pairs of struts on the fuselage, and there is only one additional pair of struts on each side of the fuselage. The fuselage is in 3-ply wood, and is very short. The tail is similar in general design to the pre-war Dorand, it is a biplane, one elevator being above the fuselage and the other below it. The engine is an Opel-Argus of 180 h.p. The machine is equipped with a fixed machine-gun firing through the airscrew and a second one mounted on a movable turret at the rear; there is a camera and bomb-dropping device. ("L'Aerophile," Dec. 1-15, 1917, and Jan. 1-15, 1918.)

NOTE.—The following additional particulars regarding the Hannoversche Wagon Fabrik have been obtained from an aeroplane brought down on the British front in France recently:—

Wings.

The upper wing is 12in. above the top of the fuselage, and since the centre section is cut forward to the back of the rear spar, an excellent field of view is provided.

* It is suggested that the distance of the C.G. aft of the radiator face is incorrectly given and that it may be 0.66 feet.

The fastening of the butts of the wing-spars is of uncommon design. The wing is placed in position by being pushed in towards the fuselage over metal eyes or balls mounted on the longerons. It is then moved rearwards a distance of half an inch, and the neck of metal balls on the longerons and on the centre section is engaged by the edges of the metal box on the wing spars. A vertical pin is pushed through the metal box passing behind the ball of the fuselage fitting to prevent the wing moving forward, thus keeping the ball fitting locked in the box.

All wings are camouflaged yellow, green, pink, and blue in soft colours and in small angular areas.

Upper Wings.

	ft.	in.
Extreme overall length of machine	25	$6\frac{1}{2}$
Span (of which 8ft. 8in. is centre section) ...	38	3
Chord	5	11

Chord Dimensions.

Leading edge to centre of front spar		10
Spar centres	2	$7\frac{1}{2}$
Centre rear spar to trailing edge	2	$5\frac{1}{2}$

Lower Wing.

Span	36	10

Chord Dimensions.

Leading edge of centre of main spar		$7\frac{7}{8}$
Spar centres	1	$9\frac{3}{4}$
Centre of rear spar to trailing edge	1	$9\frac{7}{8}$
Gap	5	3

The *Angle of Incidence* on the wings is—

Bottom wing	$5\frac{1}{2}°$ at fuselage.
	5° at struts.
Top wing	5° its whole length.

Ailerons.

Ailerons are fitted on the top wings only, and the aileron surface is partially balanced, roughly 1 sq. ft. of the surface being in front of the hinge line.

Empennage.

The empennage has double superimposed surfaces of the following dimensions, approximately:—

	ft.	in.		ft.	in.
Each bottom plane	3	4	×	4	1
Upper surface	6	7	×	1	$5\frac{1}{2}$
Gap	3	3			
Upper elevator (overall)	6	7	×	1	4
Lower elevator (overall)	6	11	×	3	8

Other dimensions are as follows:—

	ft.	in.
Rudder (depth)	3	9
Rudder (fore and aft width) ...	1	10

Tailskid.

The tailskid is not provided with swivel mounting, but has a solid metal shoe with a convex underside.

Radiator.

The radiators are placed in top centre section, and have an area of 16in. × 27in.

A metal ring is in position on the underside of the radiators within reach of the pilot. This is apparently intended to carry a semi-circular disc to act as a radiator shutter.

Armament.

The armament consists of 1 Spandau gun forward, firing through the propeller, and a second gun on a ring mounting for the gunner.

The Spandau gun receives sufficient heat from its proximity to the exhaust manifold, but leads and push-in sockets are provided for electrically heating clothing and gun for the observer.

Camera.

Provision is made for the use of a camera through a hole in the bottom of the fuselage, which is covered by a sliding panel, operated by wires and pulleys, when the camera is not used.

General.

The fuselage is 4ft. 7in. deep at the gunner's cockpit, and 3ft. 2in. wide.

"Rumpler" Biplane C.4.

This machine is a two-seater tractor biplane of reconnaissance type. Its performance compares well with that of a scout machine as regards maximum horizontal flight speed and its climb is given as about 16,000ft. in 34 minutes.

The following are the principal dimensions:—Span of wings: Upper, 41.4ft.; lower, 40.1ft. Length of fuselage, 27.6ft. Maximum height of machine, 10.7ft.

The wings are swept back 3°, and have an upward dihedral of 2° or $2\frac{3}{4}$° and a forward stagger of 2ft. Their plan forms are trapezoidal, the tips of the upper wing being raked so that the leading edge is the shorter, and those of the lower wings simply rounded, so that the maximum span occurs at the front spar. The chord at the root of the upper wing is 5.6ft. and of the lower wing 4.3ft. The angle between the thrust axis and the wing chord is about 5° in some examples, and varies from root to tip in others. Ailerons are fitted to the upper wings only, and are each of a length a little less than a quarter of the span; in width they vary from less than 2oin. at the inner end to 25in. at the tip. The gap between the wings measured from spar to spar is 6ft. 1in. The total wing area is 360 sq. ft.; upper, 215 sq. ft., and lower, 145 sq. ft.

The tailplane has a nearly semicircular leading edge, and the elevators are slightly balanced and of area about two-thirds that of the fixed tail. The triangular fin and unbalanced rudder are similar to those of the Rumpler C III. The control and stabilising surfaces at the tail have a framework constructed of steel tube, as is the usual practice in German aeroplanes.

The airscrew is a Heine 10.4ft. diameter, and carries a conical fairing in front. The capacity of the petrol tanks is sufficient for a flight of about four hours. The six exhaust pipes are united into a single streamline tube discharging above the upper wings. A honeycomb radiator is attached to the two forward body struts, and is fitted with shutters to regulate the cooling. The undercarriage is of the usual type. The pilot occupies the front cockpit, and the rear cockpit carries a machine-gun turret. Arrangements are made for reconnaissance photography and for bomb-dropping. ("L'Aerophile," Jan. 1-15, 1918.)

The Design of Air Turbines.

Air turbines have come into increasing use for aircraft in the last few years owing to the greatly extended use of radio apparatus, searchlights, stabiliser servo-motors, etc., which render the provision for generating considerable quantities of electrical power independently of the engine absolutely necessary.

The method of design discussed in this article is based on the well-known

airscrew theory of Drzewiecki and Lanchester in which the airscrew blade is considered as made up of elementary sections each functioning as an aerofoil, and the properties of the aerofoil being obtained from wind tunnel tests. Thus the procedure in the design of air turbines is very similar to that ordinarily adopted for airscrews.

An example of the design of a six-bladed air turbine is given, for which an efficiency of 81 per cent. is calculated. It is pointed out that in considering the overall efficiency of the air turbine as a generating device this efficiency of 81 per cent. should be multiplied by the efficiency of the airscrew of the aeroplane, that is, by about 0.75, making an overall efficiency of about 60 per cent.

Air turbines may be constructed in either wood or metal; if the former, the method is a direct adaptation from airscrew practice; if the latter, castings of light alloy are generally employed. ("Aviation," Feb. 1, 1918.)

Physical Properties of Aeroplane Woods.

This article is based on wood tests conducted at the Forest Products Laboratory, Madison, Wisc., and refers principally to the three most common woods used in aeroplane construction, viz., spruce, ash, and white pine. In searching for a wood that is light, has a high modulus of rupture and of elasticity, and is moderately hard, spruce has been found to give the most satisfactory results for stressed members, while white pine, having a low specific gravity, is much inferior because of its comparative softness. The moduli of rupture and elasticity are also slightly lower than that of spruce. In the case of struts, where the elastic modulus is the decisive factor, spruce is again superior. A comparison of ash and spruce, from a standpoint of flexural strengths, favours the former for the same weight, and indicates that ash would be superior for wing spars, but, unfortunately, the increase in deflection of the ash spar over the spruce spar of the same strength for the same load is about 39 per cent., so that the efficiency of an ash beam is lower, and dangers due to deformation of the wing structure increased. The final conclusion is thus in favour of spruce.

The article states that the importance of variations in strength according to different positions of the wood in the tree have been over estimated, and are mainly due to variations in specific gravity and moisture content. Tests on 26 species of woods at 15 per cent. moisture conducted at the laboratory give the following results:—

Compression parallel to grain (1 lb. per sq. in.) $= 10^4 \times$ sp. grav.
Modulus of rupture (1 lb. per sq. in.) $= 2 \times 10^4 \times$ sp. grav.
Modulus of elasticity (1,000 lbs. per sq. in.) $= 2{,}800 \times$ sp. grav.

Curves are given showing that the effect of increasing the moisture content is to decrease rapidly the moduli of elasticity of rupture, and the compression parallel to the grain up to the fibre saturation point, after which they remain constant. It is suggested that all wood tests for strength and elasticity should include determinations of the moisture content and specific gravity. The following details are given regarding the mechanical tests conducted at the Forests Products Laboratory:—

Static Bending.—The test specimen used is 2in. × 2in. × 30in. and is loaded at the centre having a span of 28in. The load is applied at a constant rate, simultaneous readings of load and deflection being taken.

Compression Parallel to Grain.—The test piece is 2in. × 2in. × 8in. and is compressed in the direction of its length. Deformation is measured between two collars 6in. apart attached to the specimen.

Compression Perpendicular to Grain.—The test piece is 2in. × 2in. × 6in. long and is laid upon its side. The pressure is applied through a suitable hard metal

plate 2in. wide laid across the centre of the piece and at right angles to its length. But one-third of the surface is directly subjected to compression.

Hardness.—Hardness is tested by measuring the load required to embed a 0.444in. ball to one-half its diameter in the wood.

Shearing Strength Parallel to Grain.—The shearing test is made by applying force to a 2in. x 2in. lip projecting from the side of a block. (G. H. Congdon, "Aviation," Mar. 15, 1918.)

NOTE.—The reference above to the effect of moisture in test specimens is of interest and capable of wider extension to other materials than timber which are affected by the quantity of moisture present in the test piece, as much more comparative values are obtained. This principle has been recognised in the testing of fabrics with advantage.

AERIAL TRANSPORT.

Italy's Plans for Postal Aeroplane Routes.

This article, published in the New York periodical "Aviation," is based on an announcement made by Signor Delmati, Director-General of the Italian Post Office, in the "Rivista dei Trasporti Aeri," that Italy now proposes to set up an aerial mail service between the Mother Country and her North African colonies, and on the views expressed by Signor Caproni, the well-known constructor of large multiple-engined aeroplanes, in an interview. The announcement is of particular interest in view of the proposed creation by the U.S. Post Office Department of a postal airplane route between New York and Washington.

It would appear that the experience gained by the establishment last summer of an experimental seaplane service between Continental Italy and Sardinia has been sufficiently encouraged to justify this further enterprise on the part of the Italian Post Office Department.

In considering the future development of public air services regard must be paid to the limitations which at present exist, such as, for instance, the relatively small cargo which can be carried by even the largest aeroplane, and the limitations imposed on the reliability of the service by the vagaries of weather conditions, these applying especially to the northern countries of Europe, where fogs are prevalent during long periods of the year. Thus for a certain time the coming public air services may be expected to be limited to linking up localities which possess no other modern means of transport or which are so far distant from one another that the creation of an air line will serve materially to reduce the time of travel.

The geographical and climatic conditions applying to Italy and her North African colonies, coupled with her capability of designing and manufacturing large aeroplanes, place her in a particularly favourable position for taking the lead in establishing commercial air routes. From Turin to Syracuse by train takes 36 hours; from Syracuse to Tripoli by steamship takes 27 hours, there being a pre-war service of four trips per week. It is estimated that with an air service the time could be reduced to about one-third, including the time required for stoppage at ports of call. In order to carry the normal pre-war mail of 4,000 kg. per week from Italy to Lybia a daily air service with aeroplanes having a cargo capacity of 600 kg. would be sufficient. A similar aeroplane mail service could well be set up between Italy and Cyrenaica; the amount of mail in this case approximated to that carried to and from Tripoli, but only one trip a week was made. In addition, there is a strong case for making interconnection by aeroplane routes between the principal cities of Tripolitania and Cyrenaica, because the shifting sands of Lybia make the construction of railroads a very expensive and hazardous undertaking. ("Aviation," New York, Feb. 15, 1918.)

METEOROLOGY.

Stratification of the Atmosphere.

This article, "Considerazioni sulla Tecnica dell'Esplorazione Atmosferica," continued from the previous number, discusses the changes in the velocity and the direction of the wind at different altitudes, as obtained from the records of numerous pilot balloon ascents. A table gives the results obtained from three ascents on May 14, 1917, up to an altitude of 2,700 metres. One of these shows a variation in velocity from less than 2 metres per second at low altitudes to a velocity greater than 30 metres per second at a height of 2,500 metres, accompanied by a change of direction of nearly 90°. The observations were taken by the use of a single theodolite.

The writer (Dr. Giuseppe Crestani) points out that the changes in the wind from one strata to the next are often irregular, but are, nevertheless, on the whole, continuous, and he refers to the well-known lack of local uniformity throughout the atmosphere, especially as regards horizontal gusts and vertical up and down currents.

A conclusion is drawn that there is a real stratification of atmosphere which is separated primarily into two distinct parts. The lower portion, which is arbitrarily limited to a height of one kilometre, is largely affected by the topographical configuration of the surface of the earth, and has a diurnal period. On the other hand, the conditions in the upper strata are determined by barometric and thermometric conditions, and especially by the general distribution of the isobars. ("La Rivista Italiana di Aeronautica," Feb. 28, 1918.)

RECENT PUBLICATION.

"Textbook of Naval Aeronautics," by Henry Woodhouse. Introduction by Rear-Admiral Bradley A. Fiske, U.S. Navy. New York: The Century Co., 1917. $6.00. Illus. 277 pp. 4to.

Deals with, amongst other subjects, aerial strategy and tactics, aerial attacks on ships at sea, torpedo planes, attacking ships with aircraft guns, aircraft motherships, submarine hunting by aircraft, locating submerged mines, naval anti-aircraft defences, administration of naval aeronautic stations, United States and British orders, rules and regulations, training of aviators, aerial navigation over water, aeroplane guns and aerial gunnery, spotting the fall of shots, bomb-dropping from aircraft, aerial photography, radio-telegraphy, night flying, instruments for aerial navigation, U.S. Navy aeronautics, naval militia aeronautics, aerial coast patrol, evolution of the seaplane and the flying boat, naval dirigibles, construction and operation of kite balloons, evolutions of the aero-motor, aeronautics in relation to naval architecture, aerodynamics, identification marks.